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Evaluating the effectiveness of variable message signs location scheme in parking guidance system

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Abstract

Variable message signs (VMS) along with the released guiding information are indispensable components of parking guidance system (PGS). The location of VMS significantly influences the operation effect of PGS. The techniques to evaluate the effectiveness of variable message signs location scheme are discussed in this paper. On the basis of the existing research on the evaluation index of PGS, an index system that reveals both direct and indirect benefits of VMS location scheme is proposed. Then indexes are allocated with appropriate weights based on fuzzy clustering analysis. Finally an objective evaluation method could be obtained.

Keywords: Variable Message Signs, fuzzy clustering analysis, evaluation index system

1. Introduction

Along with the development of urban population, car ownership and usage increases every year, which has resulted not only in serious traffic congestion, but acute parking shortages as well. Cities have introduced Intelligent Transportation Systems (ITS) containing series of technologies to solve imbalances between traffic demand and supply, among which Parking Guidance Systems (PGS) are an important component.

Parking Guidance Systems, mainly suitable for large and medium-sized parking facilities, are widely used in government buildings, large hospitals, railway stations, shopping malls and other public parking lots. The main working purpose of PGS is to guide drivers to quickly find spaces, which can save time and energy. In nowadays china, parking guidance information is mainly released on variable message signs (VMS) and VMS's location in the traffic network significantly impacts the effectiveness of PGS. Thus researchers proposed plenty of methods

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to generate optimal VMS location schemes (Zhenyu Mei, 2012) and the methods to simulate traffic assignments under the influence of a certain VMS location scheme. Therefore, PGS evaluation techniques are then proposed to objectively reveal the benefits of suitable VMS location schemes based on the traffic assignments results (Gallo, D'Acierno, & Montella, 2011). McDonald suggested that substantial economic benefits can be achieved with integrated VMS strategies after trials, behavioral monitoring and observation (McDonald, Richards, Morris, & Sharpe, 1998). Shao studied drivers' response behavior to VMS and built an evaluation model of VMS information service based on the multinomial logit model (Chun-fu, Chun-jiao, Chang-qing, & Liang, 2010). However, these researches only focus on users' benefits or economic efficiency of VMS location scheme, which are lack of a synthetic evaluation system. Zhuge carried a study on the effect evaluating system of VMS, where five evaluation indexes is proposed and their evaluating system was proved efficiency based on a region network of Beijing (Zhuge, Shao, Zheng, & Qiao, 2012). Hu proposed evaluation principle based on the evaluation index system and then put forward a two-phase evaluation index system(Guo-zheng, 2012). These researches put out plenty of indexes but seldom referred to how to allocate suitable weights among them.

This paper selected ten indexes from the former researches mentioned above. These indexes reveal the effect of VMS location scheme in an all-round way, including user's benefits, effects on traffic network, system investigation and environment influence. Applied with the multi-layer traffic simulation model proposed in , the values of these indexes are calculated based on traffic assignment result under the VMS location scheme. Thereafter, these indicators are objectively weighted based on fuzzy clustering analysis and rough set theory. At last an impersonal evaluation method is obtained.

2. Principles for Establishing Evaluation Index System

The evaluation on the effect of VMS location scheme consisted of the evaluation on both direct and indirect benefits. The index system should be built obeying the principles as follows.

- **Conciseness**. The overall situation and the specific characteristics of VMS location scheme should be reflected comprehensively with the least evaluation index.
- **Objectivity**. The evaluation index should be ensured to be objective and impartial. The data basis should be reliable and accurate and the evaluation methods should be scientific.
- **Scientificity**. The selected index, the index weight, the basic data and the calculation methods should be all on the basis of scientific theory.
- **Practicability**. In order to illustrate the issues intuitively, the index should be chosen as easy as possible to obtain and quantify.

3. Evaluation index system of VMS Location scheme

To evaluate the effects of VMS Location scheme objectively, indexes are chosen to reveal both its direct and indirect benefits that include: level of service, operation effects, investments and environment influences. Then a comprehensive analysis was made to evaluate the specific index for each evaluation criteria. The index system was shown in figure 1.

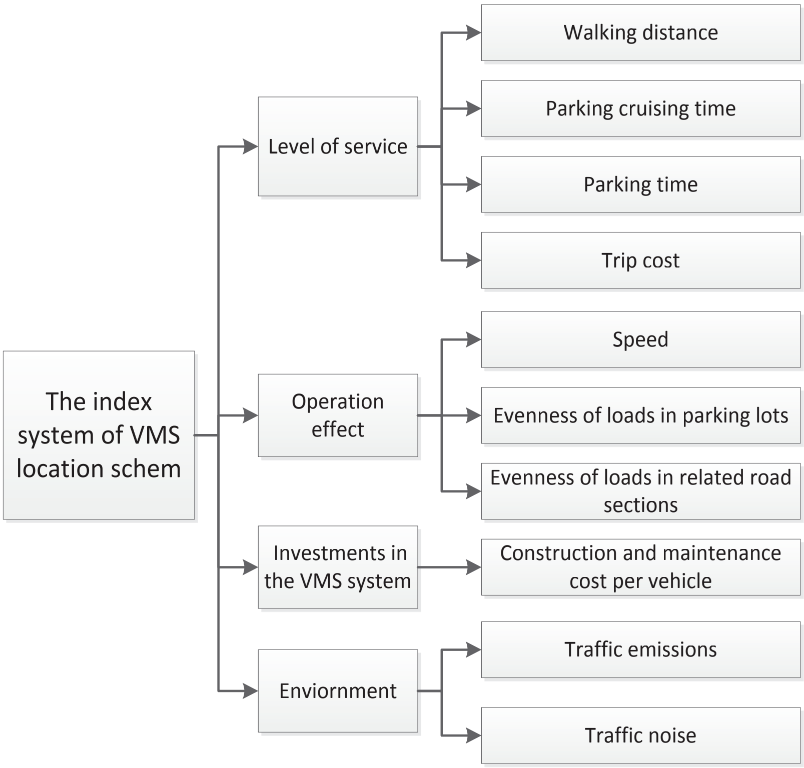

Figure 1. The index system of VMS location scheme

Walking distance. The sum of all drivers' walking distance from their parking spaces to their destinations, under a certain VMS location scheme.

$$WD = \sum \mathrm{L_w}$$

where, L_w is the walking distance for a certain driver.

Parking cruising time. The sum of all drivers' parking cruising time, which is the time they spend finding for available parking lots when they are near their destinations.

$$PCT = \sum \mathrm{T_{CUR}}$$

where, T_{CUR} is the parking cruising time for a certain driver.

Parking time. The sum of all drivers' parking time, which is the time they spend finding for available parking spaces when they have already entered the available parking lots.

$$PT = \sum \mathrm{T_P}$$

where, T_P is the parking time for a certain driver.

Trip cost. The sum of all drivers' of money expenditures during the overall trip under a certain VMS location scheme.

$$TC = \sum (\mathrm{M_{TRIP}} + \mathrm{M_{PARK}})$$

where, M_{TRIP} is the travelling cost for a certain driver, including oil cost, toll and congestion charge. M_{PARK} is the parking fee for a certain driver.

Speed. The average speed of all the vehicles when drivers are cruising for available parking lots.

$$S = \sum_i \left(\frac{\sum_{j=1}^{f_{i,r}} V_j}{f_{i,r}}\right)$$

where, V_j is the speed of the jth vehicle on the road section i. $f_{i,r}$ is the traffic volume of road section i, after the traffic assignment have been conducted under a certain VMS location scheme.

Evenness of loads in parking lots. This index evaluates that whether all the parking lots are made full use of under a certain VMS location scheme.

$$R_{PARK} = \sum_i -\ln\left(\frac{f_{i,p}}{C_{i,p}}\right)$$

where, $f_{i,p}$ is the number of occupied parking spaces in parking lot i, after the traffic assignment have been conducted under a certain VMS location scheme. $C_{i,p}$ is the capacity of parking lot i.

Evenness of loads in related road sections. This index evaluates that whether all the road sections are made full use of under a certain VMS location scheme.

$$R_{ROAD} = \sum_i -\ln\left(\frac{f_{i,r}}{C_{i,r}}\right)$$

where, $f_{i,r}$ is the traffic volume traffic volume of road section i, after the traffic assignment have been conducted under a certain VMS location scheme. $C_{i,r}$ is the capacity of road section i.

Construction and maintenance cost per vehicle. The construction and maintenance cost of a certain VMS is allocated equally among all the vehicles the system may exert influence on.

$$AM_{SYS} = \frac{M_B/N + M_M}{\sum_i AADP_i * 365}$$

where, M_B is the construction cost of a certain VMS system. N is the service life of the system. M_M is the annual maintenance cost of a certain VMS system. $AADP_i$ is the average daily number of vehicles that parks in the served area of the VMS system.

Traffic emissions. The sum of emissions exhausts in the whole road network under a certain VMS location scheme, especially carbon monoxide and nitric oxide yields.

$$E_{ROAD} = \sum_i E_i(f_i)$$

where, $E_i(f_i)$ is sum of the emissions put out on road section i, which is a function of the traffic volume f_i. Detail method to calculate this index is shown in (Lv & Zhang, 2012)

Traffic noise. The decibels sum of noise generated in the overall road network under a certain VMS location scheme.

$$N_{ROAD} = \sum_i N_i(f_i)$$

where, $N_i(f_i)$ is decibels sum of noise put out on road section i, which is a function of the traffic volume f_i. Detail method to calculate this index is shown in (Yamamoto, 2010).

4. Weight indexes by fuzzy clustering analysis

To assess the weight of indexes in the VMS evaluating system is a significant part of the VMS location evaluating process, yet which is a hard problem with multiple factors and ignorance of the relationship among evaluating objects. Thus a method combined fuzzy clustering analysis and entropy method was introduced for its excellent ability in solving this kind of uncorrelated multiple factors problems (Ring D O, 2006).

To weight the tem indexes mentioned above, we first apply fuzzy clustering analysis and rough set theory to classify the effectiveness of different VMS location schemes according to these indicators and then introduce an F- statistics to calculate the weighted mutual Information. In addition, to consider the degree of dispersion of the information, we proposed a concept called the entropy of the relative intensity. Thus a method to allocate

impersonal weight of indexes in the VMS evaluating system is obtained.

4.1. Mutual information based weighting method

4.2.1. Classifying by the fuzzy clustering analysis

Suppose there are evaluating indicators counted m, evaluating objects counted n, then forms an original indicators value matrix X(n,m), whose size is (4036,4) in this paper.

Normalize this matrix to get the fuzzy similarity matrix and then obtain a fuzzy equivalent matrix by fuzzy equivalence closure method. After an appropriate threshold value was determined by experiment, we can then classify the citizens' travel movements according to fuzzy equivalent matrix and F- statistics.

4.2.2. Definition of the weighted mutual information

Weighted mutual information is mutual information weighted by the F-statistics. In the m indicators, n evaluating objects evaluation problem, the weighted mutual information of ***j***th indicator is defined as:

$$I_{\lambda_{jB}}(C_{jB};C_B)=F_{j\max}H(C_{jB})-F_{\max}H(C_{jB};C_B)$$

In which C_B is the optimal classification set. C_{jB} is the optimal classification set when the ***j***th indicator is removed from the original indicators value matrix. H is the entropy of the classification data set. F_{jmax} is the F-statistics corresponding to the optimal threshold value for C_{jB}.

4.2.3. Definition of the mutual information based weight

As the $I_{\lambda_{jb}}(C_{jB};C_B)$ reflects the quantity of information remained in $C_B$when the ***j***th indicator is removed from the original indicators value matrix, the more important the ***j***th indicator is, the smaller the $I_{\lambda_{jb}}(C_{jB};C_B)$ will be. So we introduce M_j to measure the importance of the ***j***th indicator:

$$M_j=\lambda_{jB}\frac{1}{I_{\lambda_{jB}}(C_{jB;}C_B)} \quad (j=1，\ 2，3，4)$$

In which, λ_{jb} is the optimal threshold value for C_{jB}. $I_{\lambda_{jb}}(C_{jB};C_B)$ is a weighted mutual information for C_B and C_{jB}.

Therefore the weight basing weighted mutual information is defined as follow:

$$\omega_j^{'}=\frac{M_j}{\sum_{j=1}^{m}M_j}$$

4.2. Relative intensity entropy based weighting method

4.2.1. Definition of the relative intensity entropy

The relative intensity entropy is introduced to evaluate the dispersion degree of the data:

$$H_j = \frac{\sum_{i=1}^{m} P_{ij} \log_2 P_{ij}}{\sum_{i=1}^{m} \frac{1}{m} \log_2 \frac{1}{m}} = \frac{\sum_{i=1}^{m} P_{ij} \log_2 P_{ij}}{\log_2 m} \quad （j=1，2，3，4）$$

In which $P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, j = 1,2,3,4$

4.2.2. Definition of the relative intensity entropy based weight

We suppose that an indicator with discrete data contains larger quantity of information. In another word, when $x_{1j} = x_{2j} = \cdots = x_{mj}$, we can assert that the data of ***j***th indicator is very steady, its H actives the maximal value and it contains smallest information quantity. Therefore, it weighs low and this indicator is insignificance. According to this assumption, we definite the weight basing relative intensity entropy as follow:

$$\omega_j^{"} = \frac{D_j}{\sum_{j=1}^{4} D_j} \quad （j=1，2，3，4）$$

In which $D_j = 1 - H_j$

4.3. Definition of final weight

When the weights basing mutual information and relative intensity entropy are obtained, we combine them together with a parameter α, which ranges from 0 to 1. The final weight is able to reflect the nondeterminacy and the dispersion degree of the data at the same time.

$$\omega_j = \alpha\omega_j^{'} + (1-\alpha)\omega_j^{"} \quad （j=1，2，3，4）$$

5. Conclusion

With the VMS gradually extensively used in major cities, it is necessary to evaluate its guiding result scientifically and systematically. Based on the research on PGS evaluation of the past, this paper compressed the index from the perspective of optimal VMS location scheme and obtained the specific index from the aspects of level of service, operation effects, system investments and environment influences. The index system was established to achieve the full usage of existing parking lots, reducing drivers' trip cost and parking time, saving investment and protecting environment. Thereafter, the fuzzy clustering analysis and rough set theory is applied, a new objective weight method is proposed, which take both the quantity of information and degree of dispersion of the information into consideration. Finally, an impersonal evaluation index system is obtained, where under the guidance of this system further examining and optimizing of parking guidance system can be achieved.

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